

# Reply to 'Difficulty in the Fermi-Liquid-Based Theory for the In-Plane Magnetic Anisotropy in Untwinned High- $T_c$ Superconductors'

We show that although our original paper contains some unprecise statements there is neither a contradiction between ARPES and INS in assuming a  $\delta_0 < 0$ , nor significant physical errors that affect our results. In particular, we did never *proved*  $\delta_0 > 0$ ; instead,  $\delta_0 = -0.03$  had been already used in Fig. 4(b) of Ref. [1].

Let us first note, that indeed a positive parameter  $\delta_0$  would be consistent with the result of a simple quantum-chemical calculation yielding  $t_a/t_b \sim (b/a)^4$ . On the other hand, the LDA Fermi surface (FS) is more complicated than the one-band model used by us. In particular, the saddlepoints are not at  $(\pm\pi, 0)$  and  $(0, \pm\pi)$ , but bifurcated considerably away from this [2]. Furthermore, we have neglected both the bonding plane band and the chain band. A recent work by O.K. Andersen and co-workers calculating the *downfolded* plane bands reproduce the LDA result in detail, but in a non-trivial way: the nearest-neighbor hopping amplitude is *smaller* along the  $x$ - than along the  $y$ -direction, and the *opposite* is true for longer-ranged hoppings [3]. Thus, using the notation of Ref. [4], one finds  $|t_{1x}| < |t_{1y}|$ . Because the first hopping matrix element is most important, we have used  $\delta_0 < 0$  in Fig. 4(b) of Ref. [1] in order to explain the anisotropy in the inelastic neutron scattering (INS) data by Hinkov *et al.* [5]. The result  $|t_{1x}| < |t_{1y}|$  makes it necessary to re-visit early ARPES data on untwinned  $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$  (YBCO) [6]. However, in contrast to our Fig. 1 of Ref. [7] in untwinned YBCO, ARPES does not observe a closing of the Fermi surface around  $(0, \pm\pi)$ . In order to see whether a closed or opened Fermi surfaces would affect our main conclusions we present in Fig. 1 the result obtained from our Fermi-liquid-based approach for  $\delta_0 < 0$  and two different tight-binding parameters. One clearly sees that, although the FS topology changes, the calculated INS response reveals basically the same result, i.e. two-dimensional and highly anisotropic with two clear maxima along the  $q_x$ -direction (see also Ref.8).

Finally, if Cooper-pairing is driven by a short-range interaction as it is believed in high- $T_c$  cuprates, then the wave function  $\psi \sim (\cos k_x + \cos k_y)$  corresponds to the  $s$ -wave component of the superconducting gap function. However, as Zhao and Li correctly pointed out [9], this admixture of the  $s$ -wave component to the original  $d_{x^2-y^2}$ -wave symmetry does *not* yield the experimentally observed anisotropy of the superconducting gap. In order to see whether this is a significant physical error we present in (e) and (f) the calculated INS response for  $\omega = 35\text{meV}$ . One clearly sees that the results are nearly independent of the particular  $d + s$ -wave gap representations.

In summary, for  $\delta_0 = -0.03$  there exists no contradiction between the calculated INS intensity and recent ARPES data. Thus, our Fermi-liquid-based theory still

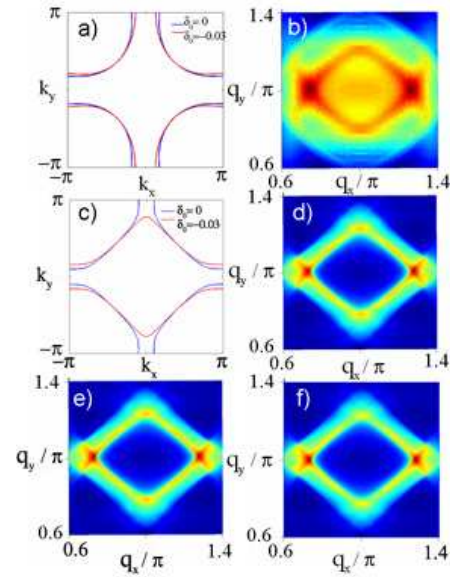


FIG. 1: (color online). Comparison of the calculated INS intensity (b) and (d) for two different Fermi surface topologies (a) and (c) calculated for two different tight-binding parameters (tb2, tb3 from Ref. [10]). Different types of superconducting gaps are compared in (e)  $\Delta_k = \Delta_0^d (\cos k_x - \cos k_y)/2 + \Delta_0^s (\cos k_x + \cos k_y)/2$  and (f)  $\Delta_k = \Delta_0^d (\cos k_x - \cos k_y)/2 + \Delta_0^s$ .

provides an alternative approach to the stripe scenario in order to explain highly anisotropic INS data.

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